Inertial Navigation System / Global Positioning System for Divers and Small Unmanned Underwater Vehicles

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LONG-TERM GOALS

The long-term goal of this effort is a compact but complete navigation package for the Navy diver that gives reasonable accuracy over the operating time intervals and distances typically traveled during direct action missions while minimizing or eliminating dependence on external acoustic transponders. Constraints in terms of size, weight, cost, performance, and power consumption have all been issues that limited this approach in the past; however, performance improvements in micromachined inertial sensors are beginning to eliminate many of the previous obstacles to the use of inertial navigation systems for personal or small-scale vehicle navigation systems.

OBJECTIVES

The objective is to evaluate and demonstrate the feasibility of compact personal navigation concepts oriented toward the Navy diver and small vehicles based on integrating small inertial sensors with Global Positioning System (GPS) technology and a small suite of other sensors to aid the Inertial Navigation System (INS).

We seek to evaluate and understand combinations of sensors and error correction/bounding algorithms that will enable the design and demonstration of a suitable personal navigation system. Therefore, specific objectives are to: 1) integrate a commercial tactical grade inertial measurement unit into a watertight enclosure along with a suitable data recording device, 2) characterize the resultant system in static and dynamic laboratory tests, 3) collect and analyze the inertial data generated by swimming with the device in a pool and in coastal waters, and 4) use the resulting information to develop navigation algorithms suitable for the diver application.

APPROACH

This effort examines candidate personal/vehicle navigation system architectures based on the projected capability of high-performance micromachined IMUs in the 2005-2007 timeframe. With the personal navigation system, we attempt to take advantage of the diver's ability to interact with the system to initiate and execute updates to the INS at appropriate time intervals during the mission. Conventional INS approaches can be employed for the most part on Unmanned Underwater Vehicles (UUVs). Raw sensor performance, integration architecture, the dynamic environment, and error correction algorithms are the four elements that must be brought together properly to correctly achieve the desired

performance levels. Kalman filter error correction algorithms depend on the system dynamic and measurement states, so the approach necessary to meet our objectives is to determine those states in sufficient detail to arrive at a set of algorithms for a given system architecture and then come up with the sensor/algorithm combination that yields the longest period of time between INS updates. A program developed to model navigation system performance for the Controls System Test Vehicle (CSTV) was employed to perform the first level feasibility assessment for this effort.

The ability to analytically determine the system dynamics model in the case of a diver in very shallow water (VSW) or surf zone (SZ) environments is limited by both the environmental uncertainty and semi-random nature of the dynamic noise introduced by the diver as well. Measurements can be used to empirically determine the dynamic state for a known set of conditions. Therefore, a breadboard system based on an existing commercial IMU will be fabricated, and experiments will be conducted in a pool to obtain a better understanding of the expected dynamic state for further algorithm development. Update schemes based on diver ability to interact with the system will also be evaluated.

WORK COMPLETED

Staffing issues constrained this year's work to a very modest level of effort that primarily entailed resolving some of the issues with respect to component selection for the breadboard diver IMU and initiation of work to develop some preliminary navigation algorithms. The breadboard diver IMU data acquisition system will be based on integrating a commercial IMU into a PC-104 processing architecture. We have performed an extensive review of a number of commercially available tactical grade IMUs on the basis of their size, power requirements, performance specifications and message interface. To accomplish our goals, the breadboard system should be built around an IMU with a performance in the 1°/hr range. The principle candidates for this application are the Honeywell HG1700 and the Inertial Science, Isis IMUs. Fabrication of the breadboard and initial data collection activities will be completed in FY01.

The process of developing a baseline set of navigation algorithms has been initiated. The CSTV algorithms[1] used in our earlier assessment and results from the initial kinematic analysis are serving as a basis for this work. We have also obtained and are evaluating the 8-state extended kalman filter algorithms developed by the Naval Post Graduate School. A commercially available INS Matlab toolkit was purchased to assist in this effort.

An initial dynamic analysis based on a simple motion analysis and some simple hydrodynamic models was completed very early in FY00. This work will be extended in FY01 through the incorporation of more elaborate human motion models.

The fundamental outstanding issue is still whether a high-performance IMU can be effectively employed in conjunction with selected other sensors in the diver's dynamic environment to provide position estimates with satisfactory accuracy. Our hypothesis is that, given sufficient IMU performance and the ability of the diver to employ several different update strategies, that a system can be designed that will provide good tactical accuracy without the necessity of a long-baseline acoustic channel or a radiating acoustic source. Data provided by the breadboard diver IMU package that will be developed and tested under this program during FY01 will help to resolve these issues.

IMPACT/IMPLICATIONS

Successful implementation of an integrated GPS/INS navigation package will alleviate several constraints that currently exist in a tactical environment. Among those are the 1000 yd to a side square range limitation imposed by the long baseline acoustic navigation technique employed by Swimmer Inshore Navigation System (SINS), as well as potential elimination of the logistical problems posed by having to survey in a baseline. Accuracy of a properly designed system should be adequate for direct action missions, and the absence of an acoustic source on the navigation package will help to preserve the security during clandestine operations. Accuracy of the envisioned system will not be adequate for precision survey type missions without arriving at a way to provide more frequent updates of the INS. However, this level of accuracy could be accomplished through the addition of a ground velocity reference such as an acoustic Doppler current profiler. Combining a small high-performance IMU with a Doppler-based diver navigation system such as the CLAM system would provide a very high level of performance over long distances.

TRANSITIONS

The most likely transition path is through the USSOCOM Special Operations Technology Development (SOTD) program or through the VSW Mine Countermeasures (MCM) Detachment.

RELATED PROJECTS

There are several ongoing projects sponsored by both ONR and external agencies that are related to this effort. Practically all of the swimming UUVs slated for demonstration in the ONR 6.3 VSW/SZ core program utilize some form of INS/GPS integration as one of the navigation subsystems. Almost all of these subsystems are based on commercially available 6-degree of freedom IMUs marketed by BEI Systron Donner Corporation or the roughly equivalent Crossbow IMU, and are used in conjunction with either an ADCP, a long-baseline acoustic navigation system or both to provide position and attitude information. Bluefin Robotics Corporation has been tasked by ONR to develop a Battlespace Preparation Autonomous Underwater Vehicle (BPAUV). This system is designed for extended duration missions, and plans are to incorporate a DARPA-sponsored, Litton-developed, INS/GPS integration designated as the LN250. Preliminary performance specifications for the LN250 are true navigation grade, i.e., an accelerometer bias of approximately 40 µg and a gyro drift rate of approximately 0.003 °/hr, thus, attaining a very high level of performance for an integrated system with a total weight of seven pounds.[2] Another program of direct relevance to this project is an effort by Draper Laboratory to develop a personal inertial navigation system for the "urban warrior". Draper has reported good analytical results by using an innovative approach that places the IMU in the heel of the soldier's boot to get zero-velocity updates.

REFERENCES

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